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Productivity In Aerospace Research and Development

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PRODUCTIVITY IN AEROSPACE RESEARCH AND DEVELOPMENT

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NASA STI FACILITY
NASA LANGLEY RESEARCH CENTER

Foreword

WE ALL AGREE that improving productivity is essential to our national well-being. Indeed we see increased productivity at the heart of some of the critical issues facing the nation today—inflation, unemployment, and energy. Improving our national productivity is the job of both industry and government.

Government, in particular, plays a much larger role in our lives. Federal, state, and local governments now account for one-third of our Gross National Product and employ one of every six civilian workers. It is essential that we in government pick up our share of this national challenge and make every effort to improve our productivity.

In this report, it is evident that NASA has done just that. Many examples are provided showing how NASA has contributed not only to national productivity, but also how the agency goes about making its day-to-day activities more effective and efficient.

We in government must continue to look hard at how we do business. We should look not only at our national impact, but also, and equally important, at how we can make increasingly efficient use of taxpayer dollars in the conduct of daily government business.

That is the challenge we face today.

December 1980

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Deputy Director
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Washington, D.C.

Preface

THIS REPORT is intended to review productivity, tangible and intangible, in the National Aeronautics and Space Administration. The concept of productivity in a Federal research and development agency is multifaceted and complex. There are at least four approaches which we feel should be considered:

(1) The contribution of NASA to national productivity external to the agency.
(2) The use of new technology to increase the output of NASA's R&D effort.
(3) The achievement of management improvement which involves planning, organization, staffing, direction, and control.
(4) The efficiency with which the agency's civil service labor resources are used to produce goods and services.

The first approach focuses on external effects of NASA research and development. The next three approaches focus on internal operations. This report is intended to explore these four different aspects of productivity and examples of NASA's accomplishments in each area.

It is hoped that these approaches will help to convey the message that Federal government agencies can be and, in fact, are efficient, effective, dedicated to increased productivity, and responsive to real public needs.

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Chapter 1

Background

THE LAG IN PRODUCTIVITY GROWTH has been an important U.S. problem for the last ten years. During this period, the nation's productivity growth has been less than half of that of the preceding ten years, and less than that of Japan and West Germany.

Over the years, productivity has come to mean the number of acceptable units produced in a given time—the number of shoes per work day or the number of castings per work week. This traditional measurement requires a count of the number of units produced and the time taken, after which it is easy to derive the productivity data. But what if work does not create countable units?

The Office of Personnel Management (OPM), assigned responsibility for improving productivity of Federal departments (Appendix A), has published a broad definition of productivity:

> . . . productivity is the measure of individual or organizational performance. It is not only efficiency (the ratio of output to input) but also effectiveness (to what extent the output satisfies program objectives). Put another way, productivity is concerned with both "doing things right" and "doing the right things." So it involves not just how much of a product is produced—or a service delivered—and at what cost, but also quality, timeliness, and responsiveness. . . .

OPM's definition includes:

(1) increasing efficiency;
(2) increasing the usefulness and effectiveness of services or products;

(3) increasing the responsiveness of services;
(4) decreasing costs; and
(5) decreasing performance times.

Within a broad government perspective, the OPM approach is applicable, particularly with regard to decreasing the costs of public services and increasing responsiveness. However, the OPM definitions really don't apply to a mission-oriented research and development agency despite the fact that the agency's accomplishments and innovations may contribute in a major way to national productivity. For an agency working at research and development, the mission is to push back the frontiers of science, investigate the unknown, create new or improved technology, decrease the time investment in R&D, improve the quality of the work, improve the efficiency of the use of available resources, and reduce the total costs.

Within an R&D agency, only some of the traditional methods of measuring productivity are valid. Analysis of NASA's experience indicates that only about 20 percent of its total civil service effort is amenable to traditional techniques for measuring productivity. These are in areas of general services and technical support where outputs are reasonably structured, routine, and repetitive. But how does one measure the productivity of research that produces new knowledge, new products, and, indeed, whole new industries? How does one measure the productivity of the thought process? Obviously, it must be done retrospectively, by an analysis of the convergence and application of the results of scientific and technological advancements. As an historical example, let us look at the first successful powered flight of a heavier-than-air vehicle by the Wright brothers at Kitty Hawk, Dec. 17, 1903. This was the culmination of many years of experimentation and development engineering by the Wrights. At that time, no one gave a thought to its contribution to the nation as an instrument of productivity. It is only in retrospect that one can begin to comprehend the impact of what followed; the

rapid evolution of the aviation industry, now the aerospace industry, and its contributions to national employment, productivity, and world leadership in commercial and military aircraft.

Chapter 2

NASA's Contributions to National Productivity

THE NATIONAL SPACE ACT OF 1958 requires that space activities materially contribute to: "The preservation of the role of the United States as a leader in aeronautical and space science and technology and the application thereof to the conduct of peaceful activities within and outside the atmosphere." NASA's contributions have occurred over a period of about 20 years. During this period the span of time between the development of new technology and its applications has steadily diminished. This has become evident in the breadth and scope of the application of NASA's technology. What is the nature of these contributions? Are they worth the investment made in the aerospace program? What are the returns? Let us look at some examples.

COMMERCIAL COMMUNICATIONS VIA SATELLITES

One of the greatest NASA contributions to national productivity has been the development of satellites for commercial communications. This not only spawned a new international industry, but also has touched the lives of virtually every person on Earth. International communications via satellite was the first space activity to reach commercialization. The application was started by the INTELSAT, in which COMSAT is the U.S. partner. The reasons for the swift application are simple. Satellites could provide television service that existing undersea cables could not. There were few regulatory barriers to the establishment of communications on a worldwide basis and the cost advantages were tremendous.

Today, 104 countries hold investment shares in INTELSAT, and the owners' equity is approximately $550

million. That investment in the space segment is overshadowed by the several hundred Earth stations and supporting terrestrial communications circuits in the network. At the end of 1979, there were 222 Earth stations providing direct satellite communications to 124 nations. An entirely new commercial market sprang up to provide the needed equipment, appearing while the research and development was still under way. Since the first commercial satellite was placed in orbit in mid-1965, INTELSAT's annual revenues have grown steadily, exceeding $200 million in 1980. At the same time circuit costs have been greatly reduced. INTELSAT charges for transatlantic circuits are only 15 percent of the initial charges in 1965. These advantages for overseas callers are now starting to be realized for domestic long-distance communications via satellite. The first U.S. domestic communications satellite was Western Union's Westar I, launched in 1974. Now three Westars have been joined by two RCA SATCOMS and three Comsat COMSTARS, which are leased to AT&T. These satellites have enabled the distribution of television programs at low rates to cable TV companies throughout the United States. Four more companies have applied for permission to operate domestic satellites, bringing to 22 the total planned domestic communications satellites between 1980 and 1986. These satellites promise to lower long-distance telephone rates significantly, and bring many new communications services. One promising new service, in terms of productivity, is video teleconferencing. If this service can be successfully provided at a reasonable cost, it could reduce business travel and make substantial savings in the cost and time required to conduct business.

During the initial years, each Earth station cost $6 to $10 million, and at this cost, there were very few, mainly located at key trunking nodes to handle large volumes of collected traffic. As new technology emerged from NASA's R&D efforts, the power level of the signal relayed from the satellite increased and the cost of the Earth station decreased. Now a

suitable small dish antenna costs about $10,000.

An example of a satellite designed for two-way communications between Earth stations located on roof tops or parking lots of factories and offices throughout the U.S., is the SBS satellite (Satellite Business System). This satellite uses a frequency band pioneered on the Communications Technology Satellite (CTS). The CTS was an experimental satellite sponsored jointly by the NASA and Canada's Department of Communications. During its three-year experimental lifetime, CTS proved that the Ku-band tested was reliable enough for commercial use in spite of the rainfall attenuation prevalent in this band. The use of this higher frequency band will permit the Earth stations to be located on the customers' premises, without the radio frequency interference with terrestrial microwave radio relay links that occur at the lower frequency C-band levels currently in use. The availability of wide bandwidth circuits can enhance productivity by enabling fast electronic mail and computer-to-computer communications as well as video teleconferencing.

USE OF SATELLITE SNOW-COVER OBSERVATIONS

Snow mapping by satellite can be an important tool in water-resources management or hydrology. A snow-mapping project, in its final stages at the Goddard center, is directed toward the following activities:

(1) Deliver snow-cover data to users in less than 72 hours during snow-melt periods,
(2) compare satellite snow-cover data to conventional snow data, and
(3) incorporate satellite-derived snow observations into runoff predictions.

Runoff predictions using snow-cover data have been made in California and Colorado. Results indicate that satellite snow-cover data are easily interpreted and provide a valuable ancillary source for improving snow-melt runoff forecasts. A cost-benefit study using results from the project indicated a 6–10 percent relative improvement in forecast accuracy could be realized by adding satellite snow-cover data. This improvement translates to a $38 million per year net saving across the

western United States; $28 million for irrigation water supply applications and $10 million for hydroenergy uses. It is expected that satellite-derived snow-cover data will become a commonly accepted predictor variable in the future with the advent of operational Earth-survey satellites.

AERODYNAMICS OF TRUCKING

The American trucking industry has the opportunity, thanks to NASA research, to save fuel on a truly large scale. The Dryden Flight Research Center directed a combination of full-scale (coastdown and over-the-highway) aerodynamic tests, wind-tunnel tests, and simulator studies that provided data projecting significant fuel and economic savings when vans and cab-over-engine tractor trailer combinations are redesigned for aerodynamic efficiency. By applying the modifications to the entire U.S. fleet of such vehicles, the fuel savings could reach 11,460 kiloliters (72,080 barrels) per day, or 4.18 million kiloliters (26.31 million barrels) per year. Significantly larger savings are indicated for follow-on derivative configurations which have been wind-tunnel tested.

NASA STRUCTURAL ANALYSIS (NASTRAN)

The NASTRAN program is a large and powerful computer program that analyzes the effects of loads on structures. Originally developed by NASA to aid design of airplanes and spacecraft, it has been used by U.S. industry to design such things as automobiles, trucks, railroad cars, ships, nuclear power reactors, steam turbines, bridges, and office buildings. The NASTRAN program, aimed primarily at large structural and design problems, is capable of treating concepts of virtually unlimited size. The NASA Structural Analysis (NASTRAN) program was developed under direction of NASA's Goddard Space Flight Center, Greenbelt, Md., between 1965 and 1970, with continuing development and maintenance the responsibility of NASA's Langley Research Center, Hampton, Va., from 1970 to 1979. Maintenance is now the responsibility of the NASA-supported Computer Software Management Information Center (COSMIC) at the University of Georgia, Athens.

The structure to be analyzed is approximated by an array of elastic finite elements, each of which is characterized by an

appropriate set of sectional properties and material properties. The NASTRAN element library contains more than 30,000 one-, two-, and three-dimensional elements, including nonlinear elements. Although other structural analysis software packages are available, none are capable of performing such large-scale analyses as the NASTRAN program nor generalized to as many applications.

FLEXIBLE, FAST INSTRUMENTATION SYSTEM

A flexible high-speed instrumentation system developed at NASA's Dryden Flight Research Center, Edwards, Calif., has proved a great boon to several industrial operations. This is best illustrated by the McDonnell Douglas Corp. with its DC-10 jumbo jet. The company installed remote multiplexer digitizer units based on the Dryden technology at decentralized points on each aircraft and found that the resulting dollar saving more than paid for the acquired systems. Compared to the company's standard data-acquisition system, the Dryden system reduced DC-10 electrical wiring from 62,484 meters to 7620 meters (205,000 feet to 25,000 feet) installation time by 3900 work-hours, and weight by 3175.2 kilograms (7000 pounds).

AQUATIC PLANT WASTEWATER RECYCLING

A development by NASA's National Space Technology Laboratories in Mississippi is the "Vascular Aquatic Plant Wastewater Recycling System." The recycling system developed there makes use of water hyacinths to remove toxic pollutants from wastewater to a degree that meets or exceeds Federal and state quality standards. The aquatic vegetation system, proposed as an alternative to the addition of an extra stage in the laboratories' existing wastewater treatment facility, has been in successful operation for five years at a saving of $1 million.

Private organizations using this NASA-developed water treatment system include Walt Disney Productions and Coral Ridge Properties in Florida, the city of San Diego, and communities in Texas and Mississippi.

The water hyacinth multiplies rapidly due to its free floating, mat-like structure with roots submerged. The growth rate allows it to absorb large quantities of nutrients, organic

materials, and other pollutants in the surrounding water. This action improves the quality of the water and helps to keep the water from becoming eutrophic, a condition in which the supply of dissolved oxygen is drastically reduced and the water is unsuited to animal life.

THE LANDSAT PROGRAM

The goal of NASA's LANDSAT Program is the development of technology for surveying Earth resources from space. The program involves the development, operation, and use of the LANDSAT series of remote-sensing satellites; they permit repetitive resources surveillance via the acquisition of multispectral image data.

The first NASA satellite dedicated to resource surveillance, LANDSAT-1, was launched in July 1972. LANDSAT-2 followed in January 1975 and LANDSAT-3 in March 1978. The satellites were placed in Sun-synchronous, near-polar orbits at altitudes of approximately 900 km (490 N. mi.). The remote-sensing instruments repeatedly view any particular area on the Earth's surface at 18-day intervals and at the same Sun angle. Their utility stems from the ability of on-board instruments to sense electromagnetic energy reflected or emitted from the Earth's surface and thereby to distinguish between surface features in considerable detail. The primary remote-sensing instrument, the Multispectral Scanner (MSS), acquires digital measurements of energy within four wavelength intervals, called spectral bands, of the visible and near infrared portions of the electromagnetic spectrum. The MSS data can be interpreted to, for example, identify vegetative species, evaluate crop conditions and production, map the extent of watershed snow cover, or locate promising mineral regions. The MSS digital data is received and processed at a number of ground facilities and then stored on magnetic tapes or transformed into imagery from which resource surveys and maps can be prepared.

Although they were designed originally as experimental systems with operating lives of a year, LANDSAT-1 operated for more than five years, and LANDSAT-2 and LANDSAT-3 are still acquiring data. Their performance and the value of

their data have led a growing worldwide community to regard the satellites as quasi-operational Earth-resource systems.

The LANDSAT remote-sensing systems are serving many users including federal, state, and local governments as well as private industry. The value of the systems has been demonstrated in many applications such as agricultural inventory, prospecting for new oil and mineral resources, charting sources of fresh water, classifying land usage, monitoring floods and mapping flood plains, and assessing the ecological impact of disturbances such as forest fires, surface mining, earthquakes, and volcanoes.

The following examples of current research and applications demonstrate the utility of the LANDSAT program.

Agriculture

Remote-sensing research and development efforts pertaining to agriculture are concentrated within a cooperative, interagency program entitled Agricultural Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS). The project addresses the development of remote-sensing technology for the provision of information required by the U.S. Department of Agriculture (USDA). Efforts are focused on the following high-priority information needs identified by the USDA: warning of crop hazards such as inclement weather, insects, and diseases; foreign commodity production forecasts; land use classification; renewable resources inventories; land productivity estimates; conservation practices assessment; and pollution detection. Utilization of the LANDSAT data increases the content and accuracy while decreasing the cost of information available to the USDA for agricultural resource management.

Forestry

LANDSAT data have proven cost-effective for the survey and monitoring of forested lands. Several states, including California, Washington, Oregon, and Idaho, have surveyed extensive forested areas. The estimated cost of a 10-million-acre survey in Washington by standard ground and air methods would have been $10 million over a two-year period. LANDSAT use allowed a comparable survey in half the time and a tenth the cost.

Perhaps the most valuable forest management application of LANDSAT is the monitoring of deforestation by both man and nature. Tropical deforestation for cultivation is a topic of major concern because of the impact on the global carbon dioxide supply. The ability to detect forest alterations with LANDSAT data has been demonstrated for diverse locations across the world. This ability will enable global monitoring of deforestation for future studies of atmospheric carbon dioxide.

Land Cover Inventory

Land-cover information is required by resource managers for planning, zoning, hydrologic models, and many other applications. Maps of general land cover can be economically derived from LANDSAT data and displayed with cartographic precision, matching national standards for 1:250,000 scale maps. As an example, a land-cover map of New England was recently produced at a cost of approximately $1 a square mile. This compares to an estimated cost of $10 per square mile for high-altitude aerial photography.

Geographic Information

Resource managers are increasingly using automated geographic information systems. These systems enable the efficient storage and rapid access and display of the spatial information required for intelligent management decisions. The capability to efficiently integrate remotely-sensed data with such systems has been developed. NASA recently cooperated with three resource managers, the Bureau of Land Management (BLM), the St. Regis Paper Company, and the Navajo Indian Nation, in the development of geographic information systems which utilize LANDSAT data. Use of LANDSAT data saved an estimated $100,000 in a BLM survey of two million acres of Alaskan land.

Pollution Detection

In the summer of 1979, history's worst oil spill occurred with the blowout of the Ixtoc I oil well in the Gulf of Mexico. More than 100 million gallons of oil leaked from the well and threatened beaches, wildlife, and fishing industries in coastal Mexico and Texas. The U.S. Coast Guard attempted to minimize the impact by tracking the oil slick and warning endangered areas. To supplement aircraft observations, NASA sup-

plied LANDSAT imagery. LANDSAT imagery mosaics, covering large areas of the Gulf and clearly delineating the oil slick, served as situation maps for the response team planning remedial action.

Summary of Applications

Many additional examples of LANDSAT applications could be cited. A recent survey by the Natural Resource and Environmental Task Force, an effort directed from the White House, identified 79 ways in which LANDSAT data are being used. The remote-sensing systems continue to provide resource managers with information—some of it previously unattainable—at lower cost and more quickly than conventional methods; impressive results from a system originally designed as experimental.

Some Earth resource managers had long recognized that the combining of LANDSAT images acquired on two or more separate dates could be very useful in detecting and evaluating changes in such as plants or ground cover. This application was hampered by difficulties in getting the images precisely registered, or aligned, until the NASA-operated National Space Technology Laboratories in Mississippi developed a computer program called OVERLAY. This completely automated technique accurately registers two sets of LANDSAT's multispectral scanner imagery. Using as clues only three to six tiny bits from an image, OVERLAY programs itself to merge one image into the other with a typical accuracy of 23-35 meters throughout a 100-by-100 nautical mile scene. This compares with about 300 meters previously and makes possible greatly improved accuracy of resource management data that can be derived from LANDSAT data. No way has been found to assign a dollar value to the use of OVERLAY but a measure of its worth is indicated by some 20 state, local and federal organizations that have implemented the OVERLAY program for their own resource analysis facilities.

LANDSAT Data Availability

LANDSAT imagery is available to the general public through the U.S. Geological Survey's EROS Data Center in Sioux Falls, S.D. The center serves as an archives and distri-

bution point for LANDSAT and other remotely-sensed data. Both pictorial imagery in a variety of formats and digital data on computer compatible tapes can be ordered by phone or mail at low cost. More than 300,000 images (each covering a 185 by 185 km. area) of LANDSAT MSS data acquired from 1972 to the present are available.

Future LANDSAT Developments

Applied research with LANDSAT data has provided a strong incentive for increasing our remote-sensing capabilities. LANDSAT data has not always proved adequate for specific resource management requirements. Instruments with finer spatial resolution or sensitive to other spectral bands have been called for. In response to these requirements, NASA has planned a new instrument, the thematic mapper, for the next remote-sensing satellite, LANDSAT-D. The thematic mapper will provide a finer spatial resolution than the MSS and will acquire data for seven spectral bands including two middle infrared bands and a thermal infrared band. The spectral bands were carefully chosen for sensitivity to vegetative and geologic parameters. The thematic mapper along with associated improvements in data transmission and processing will further enhance the usefulness of remote sensing for resource management.

MEASURING RETURNS ON RESEARCH DOLLARS

Before we take a look into other contributions to national productivity along with some predictions of specific future technological advances, let us examine the aggregate economic impact of such technological activities as those already cited. As has been shown repeatedly, technological advance has historically been a very powerful force in economic growth, marked both by wholly new products and processes as well as by vastly improved products at sharply lower costs.

Studies of the impact of space expenditures have measured long-term returns to the national economy in the form of improved productivity. These returns have ranged from 2:1 to 14:1 in value returned for funds spent. Because the methodology and actual numbers used to generate these estimates have varied among the studies, and because the

time span and economic activity measured has differed, it is not suitable to focus on any one number. But it is clear that the impacts have been positive and greater than 1:1. For research that has a specific mission objective, and for which economic growth is a secondary consideration, any return which is greater than the money spent is a positive contribution to society.

Examples of the results of the studies are:

In 1971, the Midwest Research Institute calculated a 7:1 return over 18 years from new technology such as that which NASA R&D stimulated.

In 1975 Chase Econometrics Associates calculated that returns from the pure productivity impact of NASA R&D were 14:1.

The European Space Agency also has examined the economic impact of its activities. In 1978, in a study done of the agency's major contractors, the returns from the space-related R&D were estimated at 2.7:1.

In 1975, Mathematica, Inc. measured potential gains to the economy of $7 billion over 10 years resulting from the speed-up of the introduction of just four successful NASA technological developments (gas turbine engines, NASTRAN computer programming, integrated circuits, and cryogenic insulation). This large return reflects only a very small fraction of the impact from all NASA technology, yet its estimated dollar benefit far exceeds NASA's annual budget.

Chapter 3

Applying New Technology Within NASA

BECAUSE OF ITS ORIENTATION to new knowledge, new technology, and more efficient ways of doing things, it also should come as no surprise that NASA is involved in making improvements in all its related activities such as design engineering, mission operations, conservation of energy, aeronautical research, new materials and processes, communications, and thousands of other endeavors. Automation, in particular automated data processing, has contributed tremendously to the improvement of research and development processes and the increase in R&D productivity. This section deals with the NASA use of new technology to increase R&D productivity.

ACCESS TO DATA IS DIRECT, QUICK

NASA/RECON is a nationwide computerized system providing direct access from remote locations to an immense and growing central storehouse of scientific and technical information. RECON (remote console) users are individuals at NASA installations, NASA contractors, and academic and other institutions. Scientists, engineers, and managers are furnished interactive, real-time access to NASA's massive store of information with greater effectiveness and lower cost than ever before. The transcontinental RECON network has more than 85 consoles, offering 11½-hour-a-day service in response to more than 10,000 daily commands (request steps).

By allowing direct, random access to large-scale computer storage units in ways that permit sophisticated interactive searching, RECON has substantially increased the speed and effectiveness of information retrieval and reduced the operational costs of providing this comprehensive service. Use of

the direct-access computer equipment sharply reduces the unit cost of technical literature searches, besides permitting a level of search effort impossible with previous systems. A further saving accrues from RECON's ability to put each scientist, engineer, and manager in direct contact with the central information facility. Since the user is no longer dependent on reference librarians or other intermediaries, these people are in some degree freed for other activities.

As a result of concerted efforts to improve the reliability of RECON and the efficiency of its software, the number of user requests increased significantly. The number of commands serviced grew from 1.92 million in FY 78 to 2.21 million in FY 79, a productivity increase of 15 percent.

AUTOMATION IN LAUNCH PROCESS

The Launch Processing System (LPS) for Space Shuttle launches at NASA's Kennedy Space Center in Florida is a combination of high-technology data processing equipment and software that has been integrated into a system capable of bringing a high degree of automation to the complex process of preparing and launching space vehicles and payloads. The LPS makes extensive use of minicomputers, microprocessors, large computers, data-storage devices, data communications/switching networks, measurement/command instrumentation, and sophisticated software. During Apollo launches, test procedures in the firing room were largely manual until a short time before launch. This required engineers to step through written procedures, physically observe and verify measurement readouts, and manually set console switches to initiate commands and processes. For Shuttle launches, however, the automated system will monitor measurements, verify readings, and issue commands according to test sequence requirements. Systems engineers will be alerted automatically by pre-programmed displays to any anomaly or exceptional conditions, and may initiate other automated procedures to troubleshoot and render safe the questionable subsystems. Launch-control and firing-room activities during Apollo launches required as many as 250 to

300 engineers and technical personnel at consoles to monitor approximately 8,000 measurements, plus 50 to 75 engineering personnel for software developing and post-test data analysis. In contrast, Shuttle launches, through the use of LPS, will need only about 45 systems engineers at 15 firing-room consoles to monitor up to 42,000 measurements, plus a small staff of 6 to 10 engineering-analysis personnel. LPS will thus be a significant factor in reducing the cost of Space Shuttle launches.

ARC-JET LABORATORY AUTOMATION

A new computer-controlled data acquisition and processing system has been installed in the arc-jet laboratory of NASA's Ames Research Center, Mountain View, Calif., and is becoming operational. This new system increases the available data sampling rate from about 10 per second to 1000 per second, while at the same time having an order of magnitude increase in data processing and on-line display capability. Increased processing and display capability improves the real-time monitoring and data analysis, allowing researchers to make quick decisions concerning the test objectives. The result is that facilities are used more efficiently because more and better data are obtained during each test run, and because the number of test runs can be decreased.

THERMAL PROTECTION LABORATORY AUTOMATION

A proposed computer-controlled data acquisition and processing system at the thermal protection laboratory at Ames is expected to have an even greater impact. There is currently no on-line data analysis capability and only minimal on-line data display. Finished data processing is done off-site and requires about 24 hours. The new system will give on-site processing in about one hour, greatly improving the facility's operational efficiency.

DATA COMMUNICATIONS SYSTEMS

The Ames Research Center's Data Communications System, which has been in operation since 1973, has provided significantly improved accessibility to the IBM 360/67 as well as to many other computers at Ames. This Ames system has eliminated nearly all Pacific Telephone Co. data phones at Ames, and has provided four times the bit rates to

consumers. The startup cost was approximately $450,000 and recurring costs are $50,000 per year. Equivalent telephone service would cost $500,000 a year.

COMPUTERIZED SHUTTLE PAYLOAD DOCUMENTS

The Space Transportation System Program Office at NASA's Johnson Space Center, Houston, Texas, has developed a computer-based, interactive library system for preparing and disseminating key Space Shuttle payload integration documents. The system is called the Payload Integration Library System (PILS). Payload integration documents (e.g., the Payload Integration Plan) are prepared by starting from a generic (or boilerplate) version that is generated via the IBM 360/65 computer using text-editing software known as "Word One." This eliminates the need for each document to be uniquely prepared. In addition, the document stored within the computer can be transmitted over telephone lines (Telenet in this application), using simple remote-access procedures, to any organization involved in the necessary review cycle to create a unique payload document from the generic version. By accessing documents in the computer, organizations remote from JSC can review a document, and provide comments via telephone, thereby reducing review time and mailing costs. Documents from this system are accessible and can be printed out from remote locations anywhere in the United States. All changes resulting from reviews are incorporated into the computer until a final, satisfactory version evolves. Then it is printed from the computer, signed, and distributed. Following formal distribution, any changes to the document may be made by remote access directly to the computer. The computer also is used as a library, providing an index of documents available, and current change information. Pages of any document that have been changed can be printed out remotely and incorporated into the formally distributed version of the document. This eliminates the need for JSC to distribute by mail a large quantity of change pages to keep organizations up-to-date. The interactive library system, designed to handle large quantities of documents, will significantly reduce costs,

improve productivity and effectiveness by assuring that all parties have access to the most up-to-date information. Implementation represents a decrease of 60–70 percent in costs compared to prior systems.

NON-CUSTOMIZED SPACE SUITS

The Johnson Space Center's switch to standard sizing to fit astronauts for space suits, as opposed to the custom sizing used for all previous manned space flights, has significantly reduced the number of space suits required for a larger astronaut population. At the same time, it supports increased flight frequency. During the Apollo and Skylab missions, 15 flights required 201 suits. The Space Shuttle will make 491 flights with only 44 suits. As a result, space-suit costs to support shuttle flights are a factor of almost 70 times less than for Apollo, Skylab, and ASTP. The estimated cost saving is $226 million.

SINGLE SYSTEMS TRAINER

Use of computer simulation capability at the Johnson Space Center to perform some of the systems training on a single-system basis prepares crews to make better use of the more expensive Shuttle mission simulator and has reduced the cost of training flight crews and support personnel. Orbiter single-system instruction will reduce the quantity of training hours in the more sophisticated mission simulator by approximately 1200 hours/year. The result is a net saving of approximately $1.7 million per year of facility instruction which is more readily available to the flight crew. Single-system training has also minimized scheduling problems for use of the mission simulator.

VERIFICATION TEST SYSTEM

During Space Shuttle approach and landing tests, it became obvious that data-analysis time was too long; days passed before data were available at the Shuttle Avionics Integration Laboratory (SAIL). To alleviate the problem, a computerized test system was designed and installed. An especially useful result is the provision of quick-look data and parametric analysis to determine test segments for which in-depth data analysis is essential. The system is now operational and supporting the Space Transportation System avionics verification. A data-processing run requiring 3 to 4 days can

now be accomplished in 30 minutes. Such rapid operation provides the ability to structure tests dynamically to insure the inclusion of all essential parameters throughout their significant range. Efficiency has been greatly improved, since users no longer wait several days between tests for additional data. Data from SAIL are used by about 200 persons. To date, approximately $2 million has been saved.

CREW ACTIVITY PLANNING SYSTEM (CAPS)

The Johnson Space Center is using advanced computer automation to enhance the production of flight check lists and crew activity plans. The computer systems provide interactive capability with flight-trajectory ephemeris and performance data, standard sequences, constraints, and formats. The introduction of this automated capability should improve the efficiency of the flight planner by 50 percent and reduce document-production effort by 90 percent. These enhancements apply to both NASA and DOD crew-activity planning to be developed at Johnson. By 1986, DOD plans to use a dedicated CAPS system in the Consolidated Shuttle Operations Center for DOD flights.

FACILITY AUTOMATION

At NASA's Lewis Research Center, Cleveland, six large vacuum tanks, a part of the Electric Propulsion Research Laboratory, have, through the use of solid-state logic and programmable controllers, been automated to permit unattended operation for extended periods of time. This has made the acquisition of test data much more efficient and enabled longer operating times to investigate test hardware performance. Automation permits the performing or monitoring of approximately 150 individual functions in an unattended mode. It has saved approximately nine work years of employee time, permitting reassignments to other work.

INNOVATIVE USE OF TEST RANGE

Another example of increased productivity at the Dryden Flight Research Center resulted from the innovative use of the Aeronautical Test Range. The F-15 Propulsion Project needed flight data at a large number of precisely controlled flight conditions, and these would be very difficult to obtain using normal piloting techniques. A computer in the test range was programmed to compute error signals that were, in

turn, data linked to the pilot's cockpit display to assist him in performing the task. Provisions were made to adjust these computations in real time during the flight. The net result was an estimated fourfold increase in the number of test points accomplished per flight. To obtain the same data as was obtained in 57 flights using this new technique, more than 200 flights would have previously been required.

FLIGHT SIMULATION ECONOMIES

Flight simulation at the Ames center has introduced five changes affecting productivity.

(1) Ames has developed an automated system using a microprocessor to balance rapidly the force-feel systems used on flight simulators. This force-balance system allows an additional flight time of one-quarter hour a day on each of four simulators.

(2) New computer hardware and software developments at Ames allow program transfers and background checkouts of new programs. The addition of a computer to the Flight Systems Research Lab now gives the flexibility of program transfer between the Flight and Guidance Simulation Lab, the Life Sciences Research Lab, and the Flight Systems Research Lab. This capability provides an additional program development time of about 4 computer hours per day.

(3) Since 1978, the use of new technology to improve the reliability of simulation systems has resulted in the replacement of many vacuum-tube analog computers with solid-state systems developed in-house at Ames. The changes so far incorporated save two work years per year of labor.

(4) The use of a microprocessor-based, data conversion system in manned flight simulation has resulted in a considerable savings in simulator set-up and checkout time. This system, which includes a very high speed serial communications link to the simulation computer, provides self-checking and fault diagnosis functions at the simulator and control areas that are

remote from the computer. An estimated one hour of set-up time is saved by having the system available. This results in a potential increase of simulator production time by 12 percent.

(5) A concept known as Interchangeable Cabs for motion-based simulators has been developed at Ames. Previously, the reconfiguration of simulator cockpits for different aircraft would take up to 20 percent of the available time of a motion system. Now with three interchangeable cabs for one motion system, one cab can be in tear-down and build-up, one cab at a calibration and check-out station, and one cab can be in productive use. The changeover time of cabs on the motion system is now anticipated to take a tenth of the previous internal reconfiguration time, allowing more efficient use of the Ames large motion simulators.

COMPUTER FILE HOLDS HARDWARE DATA

The materials and processes laboratory of the Marshall Space Flight Center has the responsibility for selecting, controlling, and documenting all materials and processes used in the hardware for which MSFC is responsible, including all contractor hardware. Of major concern in the control aspect of this activity is the end use of the material, any environmental factors, and the production control of each material to insure a consistent product. To enhance documentation of this activity, a computer terminal was installed for the purpose of storage and instant recall of this information. All information provided by contractors on Materials Analysis, Tracking and Control sheets is stored in this computer file and is available for quick recall in a variety of formats.

Previously the information searches required expensive and time-consuming surveys in such areas as corrosion, liquid oxygen/gaseous oxygen compatibility, stress, and flammability. The surveys typically required travel expenses for review teams. However, in the past year, four surveys were conducted which required considerably less engineering time and it is

estimated that approximately 600 work-hours were saved. The new system will eliminate the need for such surveys by both government and contractor personnel. In most cases, the required information is available in minutes rather than weeks as before. As an additional benefit, materials and processes information is readily available as required for the selection of materials for new programs or for the evaluation of contractors' proposals.

CHEMICAL ANALYSIS DONE QUICKLY

An integrated gas chromatograph/mass spectrometer/data system (GC/MS/DS) at the Marshall center is making possible real-time chemical analysis of complex mixtures at a rate and degree of precision previously unattainable and does so without extensive and laborious manual calculations. In operation, the computerized unit is injected with a sample of the unknown. Individual constituents of the unknown mixture are separated by the gas chromatograph and fed discretely to the mass spectrometer where a so-called cracking pattern or characteristic optical distribution of mass fragments is obtained for that particular compound. The associated data system scans the cracking pattern, compares it to data stored in the memory, and displays the identity of the compound or compounds responsible for the pattern.

If the proper operating conditions have been chosen, the mass spectrometer then purges itself and automatically prepares to process the next component to emerge from the chromatograph. The integrated GC/MS/DS will increase productivity by a factor of approximately 8:1 (2 days to 2 hours) over the previous manual methods for routine analyses if there are no unexpected compounds present in the sample. When totally unknown samples are encountered, the productivity can go as high as 100:1 (2-3 months to one week). The 8:1 ratio refers to (work-hours per analysis by old method)/(projected work-hours per analysis using new system). Assuming 30 determinations per year (based upon current Spacelab hardware projections), net internal savings during first year of use are estimated to be 500 work-hours, or

$8,000. A parallel intangible benefit is the fact that this equipment makes it possible to accomplish work that could not previously be done locally.

PROGRAMMED HEAT TREATMENT CONTROLS

Part of the metallurgical research effort at the Marshall Space Flight Center involves a fairly extensive heat-treating operation. In order to minimize work-hours and overtime work required to perform the complex heat treating operations required for most materials, inexpensive analog / events programmers have been installed that permit programming of temperature changes in advance. With this innovation, a technician needs to be present only when material handling is required, for loading or quenching. Before this equipment was installed, constant surveillance and overtime work for heat treatment were almost routine. A typical heat treatment operation was part of the failure analysis of a flight nozzle from a Space Shuttle main engine. Test specimens of Inconel 718 were subjected to a complex heat / cool program duplicating the cycle that had been experienced by the failed hardware. The five-day cycle included several holds at temperatures ranging between 900 F and 1900 F, with precisely controlled cooling and heating rates during the transition periods. This operation would have required around-the-clock surveillance using the old system, but with the new system the test ran unattended. Five of these cycles ran, and the personnel savings on this project alone exceeded 400 work-hours. When all factors are considered, including increased productivity and reduced expenditure of compensatory time, estimated savings from this innovation conservatively exceed 800 work-hours per year.

EXTERNAL TANK PARTS STATUS SYSTEM

The initial manufacture of the Space Shuttle External Tank used existing state-of-the-art production control computer programs. In the areas of engineering release, quality, configuration control, material, and manufacturing control there were 15 stand-alone, batch-run computer programs. These programs were sufficient to support the low-build rate planned for design, development, test and evaluation, but were not adequate for higher tank build rates required for Shuttle operations. An industry search revealed no program

that utilized a common data base, single bill-of-materials management system. Accordingly, development of the "Integrated Parts Status System" (IPSS) was begun by the Marshall Space Flight Center. The program will combine the functions of engineering release, configuration management, quality, inventory procurement, and production control into a single interactive, time-sharing, common data-base system utilizing a single bill-of-materials. This system also will include a new module to handle the manufacturing scheduling operation from the same data base. Operational usage of this system is planned for the fall of 1981. Its implementation will result in an estimated cost saving of approximately $35.5 million.

COMPUTERIZED TEST FACILITIES

Computer-based information and control systems are being employed by NASA to improve the effectiveness and greatly reduce cost associated with the operation of specialized engineering test facilities, such as wind tunnels and propulsion test cells. In actual examples, personnel required for test preparation were decreased from 10 to 4, and the time required for test runs was decreased by a factor of five. A typical experiment run that cost approximately $640,000 before, now costs on the order of $138,000. In addition to allowing more tests to be run and more data acquired, better data analysis through associated computer-driven display techniques is resulting in more precise and meaningful results.

IMPROVED DATA HANDLING FROM SPACECRAFT

A program, NASA End-to-End Data System (NEEDS), is under way at NASA's Office of Aeronautics and Space Technology to improve significantly the processing of spacecraft-acquired data, such as Earth-resources imagery. Improvements in technology, for processing the data on board the spacecraft as well as in ground-based computer systems, are aimed at a tenfold improvement in data handling capabilities.

AUTOMATED LOGISTICS SYSTEM

Computerized supply-management systems are appearing in NASA to increase effectiveness and conserve manpower. For example, in 1969 at the Kennedy Space Center, a supply system handing 68,000 line items required 510 people to operate. Today, a new system coming on-line will handle 155,000 line items but will only require 298 people to operate it.

TERMINAL CONFIGURED AIRCRAFT PILOT TRAINING

Under the Langley Research Center's Terminal Configured Vehicle (TCV) program, a number of flight simulation experiments are scheduled. These involve airline pilots from several of the commercial airlines. The avionics equipment used in the TCV program are characterized by advanced electronics situation displays. Considerable time must be spent by the commercial pilots to become familiar with the display symbology and formats. Previous practices for this familiarization have involved the use of a flight simulator at a cost of approximately $900 per hour. When used this way, the simulator was of course not available for other work. A new approach being used in the TCV program involves showing training material for the cockpit displays on a computer-fed graphics terminal under the control of the Programmed Learning and Teaching Operation (PLATO) computer program. Most familiarization work can now be accomplished using the computer system at a cost of $25 per hour. A cost comparison of the two approaches is as follows. Formerly, 25 pilots required two hours of simulator time at $900 per hour for a total cost of $45,000. Under the present method, 25 pilots use four hours each of terminal time at a cost of $25 per hour for a total cost of only $2,500.

COMPUTER USE IN AERODYNAMIC ANALYSIS

New aircraft configurations call for wind-tunnel testing of a model. But to build and instrument a model may cost between $100,000 and $250,000. Since it is not known for sure how successful the new configuration will be, a number of models are inevitably built and tested that do not yield significant advances in aircraft technology. Through the use of computers for aerodynamic analysis of a proposed concept, those configurations not likely to yield the desired results can be eliminated. It is the practice now to analyze by computer all configurations proposed for testing prior to building a wind-tunnel model. In general, four out of five ideas can be eliminated as being unfruitful in the research efforts, thus eliminating the cost of expensive models that would probably prove unsuccessful in wind tunnel tests. The elimination of four potentially unsuccessful models could save nearly $1

million. In addition, there would be savings in wind-tunnel operating costs. These savings more than offset the cost of the computer time for aerodynamic analysis.

IMPROVED FACILITIES MANAGEMENT

Use of microprocessor-based technology has increased productivity within the NASA facilities program. A broadly based pilot effort among the field Centers was initiated by the NASA Headquarters Facilities Division, using the common systems approach. It has resulted in these improved operations:

Facilities Project Data System

(1) Facility Project Data System (FPDS). This was designed to provide cost and schedule information on all facilities projects. The data are compiled at all NASA Centers and at NASA Headquarters, funneling into the Facilities Project Monthly Report. Originally, preparation of the report, including update, compilation, and review, took 165 work-days of effort agencywide. Today its preparation is done in 22 workdays.

Construction Budget Documentation System

(2) Construction Budget Documentation System. Each year this system generates two detailed budget presentations on the construction of facilities, one for the Office of Management and Budget, and one for the Congress. One is due in August and one in December. Individual project statements initially are prepared and submitted by the centers. Originally, preparing each budget book at Headquarters after the Center submissions had been received consumed from 3.5 to 7 work-months. This workload has been reduced by microprocessing to 40 work-hours for the Congressional book. For the OMB book, the effort has been reduced to about 160 to 240 work-hours. The combined total effort of 200 to 280 work-hours contrasts with the previous 865-1211 work-hours.

Facilities Maintenance Management System

(3) Facilities Maintenance Management System (FMMS). This system, which was established at the Goddard Space Flight Center, consists of an amalgamation of the Emergency Work Order and the

Preventive Maintenance procedure into a computerized system. Performance of the work originating in Emergency Work Orders was reduced by two work-years and preventive maintenance showed a reduction of fifteen work-years. In addition to the total reduction of 17 work-years, there was an enhanced level in responsiveness to emergency calls.

Space Utilization System

(4) Space Utilization System. This computer system was developed by the NASA Johnson Space Center to control the assignment of office and laboratory space in the Center, and reduce reports preparation time. Preparation of an annual 60-page report has been reduced from 90 to three hours. The system not only provides tighter controls on space requirements and assignments, but permits a reduction in tradeoff analysis effort from five workdays to one workday per request.

Work Request Tracking System

(5) Work Request Tracking System. The Work Request Tracking System (WRTS) at the Goddard Space Flight Center is an automated minicomputer system designed by the Facilities Engineering Division to track the progress of more than 800 minor construction projects a year, following them from receipt of a request through payment of final invoice. The WRTS replaced a manual tracking system that functioned mainly to identify progress. Management and customer reports were virtually nonexistent. Benefits have included a reduction in the time required to service requests; an ability to establish priorities; and provision to customers, facility managers, and safety representatives of monthly status reports on design and construction progress.

Facilities Manuals System

(6) Facilities Manuals System. The Facilities Office in NASA Headquarters prepares and updates manuals that serve as users' guides for different facilities systems. Currently there are seven key users' manuals that average about 80 pages. The Technical and

Support Facilities Branch, in conjunction with the Information Systems Division of NASA Headquarters, has developed an automated manuals preparation and control system that has decreased the workload for manuals preparation and update from 15 to two workdays per document. This has resulted in an annual reduction of effort from 105 to 14 workdays.

AUTOMATED INSTRUMENT CALIBRATIONS

At the Langley Research Center more than 15,000 instrument calibrations are performed each year to validate experimental measurements. To increase the efficiency of making these calibrations, a number of modular systems using the programmable calculator as a system controller have been developed which automatically acquire data and control the calibration of both electrical and nonelectrical instruments. The instruments include such items as amplifiers, multimeters, pyrometers, decade boxes, voltage-controlled oscillators, pressure transducers, accelerometers, gyros, and platinum resistance thermometers. Use of the automated modular systems has resulted in approximately 3200 workhours per year saved. At a contractual rate of $12.50 per work-hour, this represents a cost avoidance of $40,000. Other benefits from this automation include improved calibration turn-around time, uniformity of test procedures and data analysis, and an overall higher quality product.

HIGH-PERFORMANCE INTEGRATED CIRCUITS

Recently the Langley Center completed development of a new integrated-circuit (IC) information processor. This device solves an algebraic equation fundamental to the correlation and extraction of specific Earth resources signatures without further data processing. Based on a charge-coupled device (CCD), this new processor combines the speed of sampled analog processing with the precision of digital computers. Combined on a single IC chip are read-only memories (ROMs) containing the signatures of the desired species, signal conditioning amplifiers to prepare the raw signal for entry into the matrix manipulator, random-access memories (RAMs) to store correlative signatures that are calculated in real time, and the various clocks and peripheral logic to

maintain an organized data flow through the device. This development, called the Matrix Information Processor, represents the first in a new class of very high speed ICs used as high-performance signal processors. They make possible the processing of raw data into usable information at speeds in excess of 15 megabits/second. Such devices, when managed by small computers, will interpret information contained in Earth resource image data within seconds after acquisition. Since they will fit within the confines of the operational spacecraft, they will concentrate and enhance the information received by ground stations.

PROJECT ARIES (ASTRONOMICAL RADIO INTERFEROMETRIC EARTH SURVEYING)

At NASA's Jet Propulsion Laboratory, Pasadena, Calif., Project ARIES is continuing to demonstrate the feasibility of three-dimensional Earth position determination of extraordinary accuracy. It is now possible to measure within a few centimeters accuracy over baselines of 180 to 500 kilometers. Such precision is almost certain to improve our understanding of the Earth's crustal plates and of earthquake phenomena. The technique employs Very Long Baseline Interferometry (VLBI) and, remarkably, it uses distant quasars for a reference frame. Baseline measurements are now being made with a more mobile 4-m ARIES antenna in place of the earlier 9-m antenna. The 4-m system allows measurements at two sites per week, compared to the one-site-per-month yield of the 9-m antenna. Both systems are being updated by JPL with the new Crustal Dynamics Project Mark III VLBI Data Acquisition System. The 400MHz bandwidth of the Mark III System will significantly increase system sensitivity and overall performance.

PLANETARY DATA-COMPRESSION TECHNOLOGY

Information processing research has in recent years steadily improved image-data compression and error-protection coding. Advanced algorithms developed by the Jet Propulsion Laboratory for deep space missions now promise to enhance future NASA missions by providing significant increases in information-return capability. The data-compression and error-protection algorithms are being built into a compact computer in the camera subsystem of the

Galileo spacecraft that will explore Jupiter in the 1980s. They will increase the system's effective transmission rate from 115.2 to 287 kilobits/second, with little or no degradation in picture quality.

COMPUTER AIDED DESIGN

As befits an agency concerned with research and development, NASA has found many applications for the new concept of computer-aided design (CAD). Examples:

The Goddard Space Flight Center has significantly reduced the time and labor required for design studies of proposed Space Shuttle payload configurations. These studies investigate possible groupings of candidate experiments in order to optimize their scientific value. Previously, hand-prepared layouts required one to two work months to complete such a configuration. CAD graphics techniques have reduced this to less than two work-days. In addition, specialized software automatically calculates the mass properties of each mission configuration. The result is both error-free and a more useable format.

In Space Shuttle payload integration planning, original designs of payload / experiment modules, as well as baselined pallets and racks, are stored in a computer memory using Interactive Graphics Design Systems. The designer is able to acquire the standard elements and locate them in various configurations in a very short period of time. When a final design is decided upon, a drawing is produced. The value of the IGDS to productivity is dependent upon the complexity of the changes made. If all the modular elements are in storage, a simple change (e.g., moving a component from one place on a pallet to another) can be made by the designer in minutes using IGDS, whereas the same change on the drawing board might take an hour.

At the Kennedy Space Center, an automated drafting system (ADS), an interactive graphics system consisting of a computer and electronic input/output devices, is used to make production drawings. Manual drafting outputs have been increased about 250 percent and an annual saving of $590,000 has resulted from the use of ADS.

The Jet Propulsion Laboratory is planning a minicomputer-based CAD system to custom-design large scale integrated (LSI) circuit chips—those having less than 500 gates per chip—and very large scale integrated (VLSI) circuit chips—more than 500 gates per chip. Using improved software developed by the Marshall Space Flight Center for formatting circuit layouts, determining optional wiring paths, and simulating circuit performance, a minicomputer with a color graphics terminal will form a stand-alone LSI custom design facility.

The system for VLSI will consist of a modified Minter smart terminal, an Hitachi monitor with a DEC LSI-11/03, and customized interface hardware. The terminal will be distributed to several locations within JPL, and will be capable of interfacing with either the minicomputer system or the Caltech VLSI design system. These two systems will allow the interactive design, analysis, and simulation of alternative circuits, and thus increase the productivity of design engineers. A comparison in productivity between manual and CAD methods for VLSI is not possible for the complexity of VLSI is such that it cannot be used without computer assistance. But a comparison between manual and CAD methods for LSI can be made: With manual LSI design, the engineer geometrically lays out the chip on a drafting board and determines if the components satisfy design laws with regard to timing delays, capacitances, signal strengths, etc. If design laws are violated, he reconfigures the chip and repeats his calculations. With CAD, the computer contains the design laws and performs the iterative calculations that point out any inconsistencies. The engineer is able, via a graphics terminal, to interactively reconfigure the design based on the computer's calculations. It is estimated that the JPL LSI design facility will increase productivity by a factor of eight over manual methods. It is JPL's plan to use the CAD systems for custom circuit design and then give the finished designs to industry for actual fabrication.

The Jet Propulsion Laboratory, in the course of its earlier spacecraft programs, has produced from 12,000 to 15,000 design and engineering drawings annually. Almost all of these drawings have been produced manually, making the entire effort very labor-intensive and time-consuming. With the present maturity of powerful, relatively inexpensive minicomputer systems, coupled with interactive graphic display devices, the application of this technology to improving the efficiency of the design process becomes particularly attractive. An engineer normally visualizes and forms his concepts in geometric terms. Given the ability to graphically produce, display, change, and output high-quality design and engineering computer programming and operations, a design engineer is relieved of the monotony of a paper-and-pencil exercise. He is able to produce interactively specification drawings in a fraction of the time needed by manual methods. On average, productivity can be increased by a factor of three over conventional means. Whether the application is mechanical drafting, spacecraft configuration control, or integrated circuit design, an engineer sitting at a display terminal can develop his design visually, experiment with alternative designs, and have his finished set of engineering drawings produced by a high-speed plotter to the accuracy required for final fabrication. Based on expected improved efficiency, the estimated annual saving will be about $5.7 million after all required equipment has been acquired.

Interactive computing techniques have resulted in increased efficiency of engineers in various assignments throughout the Marshall Space Flight Center. It is estimated that this increased efficiency has improved the productivity equivalent by as much as 10 work-years of effort.

The use of interactive graphic design systems (IGDS) has significantly improved the preparation of electrical schematics, interconnect diagrams, panel layouts, and rack allocation drawings. Standard symbols, parts, and configurations

are stored in the computer memory and recalled as needed to produce a desired drawing. Using conventional drafting equipment, a typical drawing listed above might take one and one-half days to complete. Using IGDS, an operator can produce the same drawings in two hours. Multilayer printed circuit board designs using IGDS can now be accomplished in about half the time required on drawing boards. Drawing changes using IGDS offer even greater cost saving; a change can be made up to 12 times faster by IGDS than by manual methods.

In the case of the design/drafting effort used for the Solid Rocket Booster (SRB) that will help launch the Space Shuttle, a reduction in work-hours of 70 percent was realized through use of a computer-aided design system at Marshall. The cost of converting to the computer system was recovered in its first year of use. In addition, the consistency of drawings was improved and the time required to generate them was shortened. An estimated $1 million saving resulted over a three-year period.

RANGE INSTRUMENTATION RADAR PROGRAM

The updated Range Instrumentation Radar Program at the Wallops Flight Center has increased productivity by the use of a digital signal processor (computer) as the basic core of the radar system used to track sounding rockets and aircraft. The new Ka-band and mobile C-band systems use a digital computer as a major portion of the real-time processing equipment. This new state-of-the-art hardware has resulted in the reduction of manpower, maintenance, spares, electrical power, and air conditioning. It also has cut the complete system from two units to one unit of hardware. The computer-based concepts have increased the mean-time-between-failure and decreased the mean-time-to-repair. The electrical power reduction amounts to about a 40-percent saving. Manpower reduction amounts to about one work-year. Maintenance and spare parts reductions amount to about a 25-percent saving.

COMPUTER CONTROLLED BATTERY MONITORING

At Dryden, before silver-zinc batteries became the primary power source for research flight vehicles, all battery charging consisted of an eight-hours-a-day manual charging operation. Then the X-24 research vehicle, which used silver-zinc batteries, presented a problem: its batteries required constant monitoring once the cells reached a critical voltage level. Eight batteries were maintained by the battery laboratory for the X-24 project. Each battery contained 20 cells and when the cells reached critical voltage levels, they had to be monitored every five minutes. That tight monitoring was necessary to prevent overcharging of the battery. Silver-zinc cells when overcharged evolve gasses that can cause the cell case to rupture. Manual monitoring required two men to oversee the battery-charging operation constantly. The flight requirements made necessary the equivalent of seven men to process the silver-zinc batteries and the normal servicing of nickel-cadmium batteries used in other aircraft.

In 1970 a Hewlett Packard Computer Data Acquisition System was installed to permit automatic monitoring and control of the charging operation. This computer system permitted the controlling of 35 20-cell batteries (700 cells). Because of the self-checking features of the computer system, unattended charging could be performed 24 hours a day, seven days a week. This system reduced the staffing requirement to two men. Without it at least two additional technicians would have been needed to support all Dryden's research programs, with an additional three during periods of flight activity.

REMOTELY PILOTED RESEARCH VEHICLE

The Remotely Piloted Research Vehicle (RPRV) concept originated in 1968 and was first used by NASA for a flight test of the Hyper III vehicle in 1969. Success of this early program led to development of the RPRV technique as a means of obtaining test data for hazardous flight regimes. Spin testing of a 3/8-scale model of a modern fighter aircraft was conducted between 1973 and 1978. Present applications include

flight testing of hazardous concepts using an unmanned vehicle with a recovery parachute. As an example, the DAST (Drones for Aerodynamics and Structural Testing) program is to test an active flutter-suppression system on a thin flexible wing at speeds above the flutter speed of the undamped wing. Since the hazards of testing this concept are high, it is doubtful that the testing would have been done with a manned vehicle. For the DAST program, flown on a modified Firebee, the cost of the vehicle and test wing was on the order of $5 million. To fabricate a wing for a manned vehicle, with the added system redundancy that a manned vehicle would require, the minimum cost would have been on the order of $15 million.

Chapter 4

Productivity Increases From Management Initiatives

MANAGEMENT INITIATIVES, WHICH CAN result in productivity increases, typically involve areas of planning, organization, staffing, direction, and control. These may be accomplished through new or revised organization, improvements in planning, changes in manpower or skill mix, or changes to accommodate new or altered missions and programs. Management initiatives can occur at any level, from the agency head or chief executive officer to all working levels. This is not a unilateral process; it involves communication and interaction, transmittal of goals and objectives, solicitation of ideas, creation of an environment for improvement, decision making, openness about what is going on or being attempted, purposes, and continuing discussion on what can be improved and how.

Participative management, perhaps the best approach to productivity increases, is particularly applicable to R&D activities. Participative management uses a team approach for innovation and problem solving. It encourages the flow of ideas both upward and downward. It uses the skills of all participants, and profits from synergistic interaction. It fosters an atmosphere of accomplishment and creates an orientation toward efficiency and effectiveness. It establishes objectives and schedules. It promotes a sense of values and an identity with an achievement-oriented organization. It is directed toward optimal productivity because it can combine human skills and other resources in the most complementary manner.

Management initiatives that have contributed to increased productivity within NASA are illustrated by the following

descriptions of changes recently effected or still underway within the agency.

TRACKING AND DATA RELAY SATELLITES

NASA ordered development of the Tracking and Data Relay Satellites (TDRS) with the objective of increasing the reliability of tracking and data relay operations, improving data-handling techniques, and achieving economies of scale. The assignment was given to the Goddard Space Flight Center. The first of the powerful new satellites is scheduled to be launched in 1982. As they become fully operational, NASA will be able to close down ten satellite tracking stations around the world. The present operations are quite labor-intensive, having to function 24 hours a day, 7 days a week. About 5,300 contractor personnel are employed in the Goddard tracking and data system around the world. The effect of TDRS will be to reduce this number over the next five years by 2,300.

MODERNIZATION OF NASA WIND TUNNELS

NASA has had a continuing program to upgrade the operations, reliability, and output of its wind tunnels, while at the same time enhancing the safety of its personnel and improving the accuracy of the test results.

An innovation in the method of detecting laminar-to-turbulent boundary-layer transition on wind-tunnel models was recently devised at the Langley Research Center. The techniques of observing oil flow over model surfaces and using a stethoscope to detect noise changes along test surface orifices, have been employed for many years. Using new techniques, an inexpensive accelerometer, or microphone, replaces the stethoscope. The accelerometer is installed in the pressure line from the scanning valve to the transducer that measures pressures from the orifices on the model's surface. The output signal of the accelerometer is amplified for audible indication or for recording on tape. Energy is saved because the stethoscope method required two tunnel runs to obtain both pressure and transition data. Additionally, the new method permits data input for a number of data-acquisition systems, if desired.

In its modernization program, the Lewis Research Center has begun the installation of high-speed, automated data

acquisition and control systems in its large wind tunnels, the 10 by 10 foot, 8 by 6 foot, and 9 by 15 foot tunnels. These systems will allow the continuous acquisition of data in a ramp mode with a saving of 25 percent in run time, thereby permitting better use of these facilities. In addition, the systems will provide faster interpretation of data through on-line graphics, permitting more efficient and higher-quality test programs.

Since 1973, modernization and upgrading of wind tunnel data acquisition systems have continued at the Ames Research Center. As a direct result of implementing these data systems in both the Unitary Plan and the 40 by 80 foot wind tunnel facilities, there was a savings in both work-hours and energy to perform tests. In the Unitary Plan Wind Tunnels, a savings of 144 work-hours per average test resulted. The energy saved per test averaged 720 megawatt-hours. This amounts to about $18,000 over a two-week period (the average tunnel run time). The savings in energy equals $468,000 per year. On the basis of the reduced time to complete a representative Unitary wind-tunnel test, a productivity improvement of about 20 percent was achieved between 1973 and 1980. Work planned for the unitary tunnels between now and 1985 includes further improvements to data acquisition and instrumentation, new computers, and automation of tunnel operations and model-preparation shops. The total increase in productive capability resulting from these improvements and those already accomplished will be nearly 100 percent. For a representative test, energy consumption will decrease by approximately 70 percent from the 1973 value.

REORGANIZED AIRCRAFT AND GROUND SUPPORT OPERATIONS

Since flight research is a manpower-intensive activity, increasing productivity was a major goal in a Dryden reorganization of February 1979. One significant change was to place all employees who have "hands on" aircraft or ground-support duties within a single directorate. All aircraft mechanics and instrumentation technicians were placed in a single division within the Flight Operations Directorate. This decreased organizational notifications involved in getting aircraft in the

air and increased coordination among those working on the aircraft. It also made possible the establishment of an operations scheduling office that could effectively integrate scheduling of activities. In addition, Dryden was able to reduce its technician work force from 520 to 461. The effectiveness of this change is confirmed by the fact that the number of research flights has increased to 392 from 312 the previous year. An additional 1,000 to 1,500 support and checkout flights are also performed each year. This trend of increased research flight activity continued into the 1980 Fiscal Year with 85 research flights in the first quarter (normally a period of low activity due to weather and holidays), as compared to 54 in the first quarter of the previous year. This is a 57-percent increase in productivity after the reorganization.

STANDARDIZED AND CENTRALIZED MINICOMPUTER DATA ACQUISITION SYSTEMS

Centralization of both data acquisition and associated computer services has long been a hallmark of Lewis Research Center operations. Over the past three years, a system concept (named Escort) of centrally locating the online minicomputers that service the data acquisition and facility display requirements of a number of research test facilities has evolved. Currently, about 35 test facilities are being supported, via 25 centrally located minicomputers. The pool of minicomputers also supports the development of new programs. Three to four programmers have been able to provide complete programming support for all the facilities without having to leave the central area. This savings in programming labor is a factor of two to four better than individually supported systems would produce.

In addition to the programming manpower efficiencies of centralization, manpower is saved in operations and maintenance. One operator per shift provides all the support required for loading and unloading programs, scheduling maintenance, and assisting users with operational problems. First level "repair" is accomplished by switching to another minicomputer, and usually results in a facility that is back on line in a matter of minutes. The training required to use and understand the system takes less than one day, and is per-

formed on a central simulator. New operational systems are installed from one to four months following the definition of a requirement, as compared to the one to two years required for custom systems.

CENTRAL FACILITY FOR PREPACKAGING AND STOWING EQUIPMENT

The Johnson Space Center has implemented the concept of a central facility for prepackaging and stowing all loose hardware and crew equipment in reusable flight lockers for use by the Space Transportation System. The central facility will support all launch and landing sites and preclude duplication of facilities and staffing at these sites. Flight locker prepackaging and equipment-kitting operations will be accomplished at Johnson beginning with the Space Shuttle's first Orbital Flight Test. Reusable shipping containers will be used to transport lockers and kits to and from the two shuttle launch sites—The Kennedy Space Center in Florida and Vandenberg Air Force Base in California. Loose equipment will be returned to Johnson after each flight to be refurbished as required, and recycled for subsequent flights. Final preinstallation acceptance testing also will be accomplished at the Texas center. Since hardware items are prepacked for flight and then shipped to the launch sites in reusable containers with vibration isolators, humidity control, etc., no further testing prior to launch is required. The central prepackaging facility is available, flight-configured lockers have been built, and simulated stowage exercises have been conducted to test procedures and train personnel. It is estimated that this mode of operation will save the Space Transportation System $45 million over the next 12 years.

SATELLITE DATA LINK

Data-link sharing is a vital element in making research programs more productive. To support the Space Shuttle approach and landing tests at Dryden Flight Research Center in Southern California a satellite data link was established between Dryden and the Johnson Space Center in Texas. The existence of this ground station at Dryden then made it feasible to establish a Dryden link with the Ames Research Center in Northern California for the latter's tilt rotor aircraft research program. Sharing of links or portions of links

requires scheduling and coordination, but also decreases costs. The Dryden/Ames link costs are $400/hr (actual use time) and a monthly recurring charge of $8,200 over an 18-month period. These costs are two to three times lower than would be the case if the link was not shared and if Dryden had not installed the ground station for Shuttle. The link also has been used to transmit real-time flight data to NASA Headquarters, and will be used during Shuttle orbital flight tests to transmit real-time data to Johnson. For the Tilt Rotor Program, without the link for data transmission to Ames for real-time monitoring and evaluation, the minimum time between flights would need to be extended. This could have stretched the program from 18 to about 30 months, and added about $1 million to the cost.

STEAM-VACUUM SYSTEM

At the Ames Research Center's Steam Vacuum System, new operational guidelines that force facility cooperation and communication in the use of available vacuum pumping periods have reduced the system's nonproductive standby time. This has resulted in an estimated 10 percent decrease in the consumption of natural gas when compared to similar previous operations and the saving of an estimated $48,000 in one year.

MID-AIR PAYLOAD RECOVERIES

Prior to obtaining the Skyvan aerial retrieval aircraft at NASA's Wallops Flight Center, Wallops Island, Va., sounding rockets launched from the Center fell into the Atlantic, sank, and were left in the sea. Water recovery was impractical for most payloads because their missions prohibited a costly sealed, waterproof structure, and also because water recovery operations are expensive. Approximately $550,000 was spent to obtain the Skyvan, its Mid-Air Retrieval System (MARS), and to train its crews. Mid-air recoveries were made successfully on two Super Arcas payloads, two Astrobee-D payloads, and one Nike Orion payload. After refurbishment for reflight, the returned hardware was valued at $104,000. The direct operating cost for these five recoveries was $12,000 for aircraft training and operating

costs, and $4,800 for parachute reinforcement costs. During the current fiscal year, hardware valued at $409,000 has been returned for $8,000 worth of training and recovery flight time, and $9,800 in parachute reinforcement. It is anticipated that another $75,000 will be saved recovering Loki Datasonde payloads and up to $110,000 by recovering Super Arcas and Orion payloads. None of these payloads are water-recoverable.

In summary: (1) a one-time acquisition cost of $550,000 was paid for the complete system; (2) to date, $513,000 of hardware has been returned; (3) at least another $104,400 is expected to be recovered soon; and (4) the future promises increasing productivity for the system.

USE OF WORD PROCESSING

A centralized word-processing operation has been established at the Marshall Space Flight Center to prepare documents for the Procurement Office. Facilities for this operation were established within existing office space and refurbished to accommodate up to eight operators and one supervisor. Where long text-type documents are submitted that may require revisions, the word processing operation has proven especially effective. But preprogrammed forms, requests for proposals, and shorter documents also receive faster turnaround time. In 1977 the Procurement Office workload required 43 man-years of clerical support. With the word-processing group in operation and a larger workload, only 38 man-years of clerical effort are required. The reduction of five man-years equates to an annual saving of approximately $57,000.

At the Kennedy Space Center, more than 60 word processing systems (WPS) have been installed to prepare documents where significant volumes of repetitive typing are required. The output of typists has almost doubled.

Additionally, at KSC, preparation of launch procedure documentation, formerly processed on a high-cost, centrally-located computer facility, has been converted to WPS equipment. This provides versatile, lower-cost data storage

retrieval, and printing or typing capability at user locations. The services of programmers, operators, and keypunch personnel required by the central computer facility have been eliminated, and requirements for user professional/technical personnel have been reduced. The overall use of WPS at KSC has resulted in an estimated annual cost savings of approximately $1,200,000 for clerical/administrative applications and $500,000 for preparation of technical documentation.

ENERGY CONSERVATION

During 1976, NASA established a goal to reduce its utility energy consumption 50 percent by FY 1985, using FY 1973 as a base year. This goal exceeds the Federal goal established by Presidential Executive Order 12003 in 1977 for a 20 percent reduction by FY 1985 using FY 1975 as a base year.

Early conservation actions started with low-cost modifications and operational changes that resulted in "quick-return savings." These actions included: lowering of light levels; changing of air conditioning and heating set points; allowing janitorial services during normal duty hours; and reviewing of operational plant procedures to minimize demand. Early in the program, it was realized that additional energy savings would require a capital investment program and a systems approach. This approach determines the best combination of initiatives for the most cost-effective expenditure of funds. The systems criteria is basically simple amortization of project investment, and the application of an energy effectiveness index (EEI), a ratio of millions of BTU's saved per $1,000 of investment. Through FY 1980, over $50 million has been budgeted for energy-conserving projects. A total exceeding $120 million may be needed to complete the program by FY 1986. Projects range from rehabilitation of steam/hot water distribution systems to reconfiguring heating and cooling plants, and installation of a utility control/management system.

A significant investment has been made in Utility Control Systems (UCS). These UCS systems are able to monitor and control building heating and cooling systems and fluid temperatures, pumping rates, outside air and ventilation,

electrical demand, consumption monitoring, and follow an energy-optimization program.

Through FY 1979, NASA has reduced utilities energy usage (i.e., electricity, natural gas, fuel oil) by 37 percent from the FY 1973 base. This represents 12 trillion BTU's or approximately 2 million barrels of oil. This is enough energy to heat approximately 80,000 homes for one year. This also represents 18 percent of the required 20 percent goal established by the President.

Another integral part of NASA's total energy management program is the study, planning, and implementation of pilot programs using renewable energy sources such as the Sun, biomass, geothermal sites, and coal. The objectives of these programs are to strive for a national 30 percent reduction in use of petroleum-based fuels, and help stimulate national growth in use of renewable energy.

DISTRIBUTING NASA SOFTWARE

NASA uses the Computer Software Management and Information Center (COSMIC) at the University of Georgia to assist in the distribution of NASA software. In addition to the savings afforded within the space program, COSMIC has provided valuable assistance to many industrial organizations through distribution of existing computer programs as part of the NASA Technology Transfer Program. Many corporate users have reported substantial savings of both dollars and work hours as a result of programs acquired from COSMIC. One on-going activity reported an annual savings of 2000 work hours and $300,000 through the use of a COSMIC-distributed software package.

IDEA CLEARING-HOUSE CREATED

NASA formalized an agencywide program that systematically identifies, documents, and disseminates Center actions taken to improve the quality and timeliness of performance, increase productivity, control costs, and upgrade institutional operations. A network of contacts throughout the Centers was established, through which new ideas or actions are quickly identified, documented, and disseminated to all agency employees, creating an Idea Clearinghouse. This overall effort has resulted in the identification of several new

high-payoff ideas that clearly contribute to improved productivity.

MICROGRAPHICS

The increasing volume of records retained by the agency has created storage problems, and difficulties in retrieving the stored information. A NASA micrographics manager has been designated to insure that maximum and efficient use is made of micrographic techniques to reduce the space needed for retained records. Each installation has a micrographic coordinator to insure that potential applications for micrographics are fully exploited. Early evidence indicates that reduction in record storage requirements will be experienced throughout the agency, contributing to overall productivity.

Chapter 5

Summation

THIS THEN IS A SYNOPTIC account of the state of productivity in a Federal agency engaged almost exclusively in research and development. In the limited areas where the numerical measurement of productivity growth is possible, the agency shows a modest, steady, cumulative advance, amounting to about 10 percent in five years. In those performance areas where intangibles rule, only time will allow an accurate assessment of the productivity effect, when it establishes values on what innovative creations have meant for the nation and, in some cases, for the entire world.

The work areas NASA found to be amenable to the traditional work-measurement approach can be generally described as common institutional services and technical support. In Fiscal Year 1979 this work covered approximately 4,000 civil-service personnel, almost 20 percent of NASA's work force.

NASA has participated in the Federal Productivity Measurement Project since 1974. For the purpose of this project, productivity was defined as the efficiency with which an organization's civil service staff resources are used to produce measured outputs. Productivity in this system is expressed as the ratio between the volume of goods or services produced (outputs) and the quantities of labor resources consumed in their production (work-year inputs). This ratio is translated into an index, with the first year's data referenced as 100. Subsequent yearly changes in the ratio are analyzed by comparing the current index with the base-year index. The average annual productivity increase in NASA's measured

activities since 1974 has been almost two percent. The documented examples, we trust, demonstrate convincingly that the agency is being responsive to America's needs of today and of tomorrow. The future, as always, is shrouded in mist, but one guiding principle remains valid. It is that we must avoid sitting tight and overvaluing today's glittering, clever technological marvels because even more able and productive marvels are in the offing. We need only to maintain a climate allowing their emergence. The ultimate resource, of course, is people—dedicated, innovative people working together to create the next exciting era in human endeavor.

Appendix A

Federal Productivity Assignments

Realizing that productivity is a great national concern, the Congress in 1975 enacted Public Law 94-136 which established the National Center for Productivity and Quality of Working Life. The Center was intended to be the focal point of a national effort to improve productivity growth.

When Public Law 94-136 expired in 1978, President Carter signed Executive Order 12089 that established the National Productivity Council. The mission of the Council is to:

(1) work with the Executive Agencies to assure that activities designed to improve productivity in the public and private sectors are carried out in a manner that realizes maximum benefit from the resources invested;

(2) identify issues pertaining to private and public sector productivity and productivity improvement, and make assignments to Council members or other Executive Agencies for studying and resolving those issues;

(3) identify major policy issues with productivity implications for consideration by the President, including the need for legislative initiatives;

(4) serve as the focal point within the Executive Branch for liaison with elements of the private sector concerned with improving productivity, and seek the advice and assistance of business, labor and academic leaders, as well as representatives of state and local governments and others concerned with productivity; and

(5) serve as the focal point within the Executive Branch for liaison with organizations of foreign governments involved in efforts to improve productivity.

With inflation at a high level, a major way to reconcile the call for fiscal restraints and still meet public needs and services is to improve productivity in government.

The Congress recognized this need and passed the Civil Service Reform Act of 1978 with its emphasis on increasing productivity in all areas of government. The law makes productivity improvement a major objective of government. It requires that in appraising performance of senior executives, their productivity and that of the organizations in which they have leadership roles and the productivity of their subordinates will be taken into account in decisions regarding promotion, demotion, retention, pay, and bonuses. Never before has there been this kind of emphasis on government productivity in any Federal legislation.

As a consequence of the 1978 act, the Office of Personnel Management (OPM) has a major mission in productivity. This presidential assignment was intended to ensure that Federal productivity improvement efforts would receive a much higher level of attention. While there had been a general responsibility to encourage improvement of Federal productivity on the part of the National Center, that aspect had not been the major part of its work. The Center had never spent more than 5 percent of its budget on issues related to Federal productivity.

OPM was directed to exercise its responsibilities in collaboration with other Federal agencies through the National Productivity Council. The Council, chaired by the Office of Management and Budget (OMB), is responsible for assuring that all efforts by the Federal government to promote productivity are specifically assigned to particular agencies and are fully coordinated through the Council. This responsibility embraces the industrial and commercial sectors, the Federal government, State and local government.

Appendix B

Criteria Used in NASA Survey

THE CRITERIA USED IN this NASA survey to determine which elements of its organization were amenable to the specified productivity measurement approach were as follows:

(1) Each output measure should consist of units which are relatively homogeneous with respect to their labor requirements.
(2) Outputs generally should be repetitive.
(3) Output indicators should directly reflect the workloads of the organizational unit.
(4) Output measures should reflect changes in output quality.
(5) Output measures should indicate the amount of work done during each fiscal year.
(6) Output measures should reflect the final products and services of an organization.

It was found that the following areas were generally qualified for the project's measurement approach:

Aircraft Operations
Public Affairs
Audio-Visual Equipment
Reliability and Quality Assurance
Financial Management
Resources Management
Graphics
Scientific and Technical Information
Inspections
Security
Instrumentation

Supply Management (Equipment Accountability)
Supply Management (Other)
Mail Delivery and Service
Occupational Medicine
Technical Shops
Personnel
Technology Utilization
Photographic Services
Telecommunications
Printing
Traffic Management
Procurement
Transportation

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